

The Clean Way to Identify a Scalar Glueball

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The existence of a glueball has been a tough work for many years study. Utilizing the well developed QCD theory for B meson decays, we propose a new way to identify whether a scalar glueball existed or not. In the presence of mixing between glueballs and ordinary scalar mesons, we explore the possibility to extract the mixing parameters from semileptonic B decays and nonleptonic B decays. We also point out a clean way to identify a glueball through B_c decays.

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INTRODUCTION

Quark model has achieved a great success to describe hadronic states, but the QCD also predicts the existence of mesons without any valence quark, which is called glueball. The confirmation of a glueball is one of the most important topics in hadron physics and this subject has received extensive interests [1]. Lattice QCD, which is almost the only method to do calculations from the fundamental QCD, predicted that the mass of the lowest-lying scalar glueball (0^{++}) is around 1.5-1.8 GeV [2]. Several different candidates have been observed in this mass region, but there is not any solid evidence on the existence of a pure glueball. For decades, people have tried to find a way to verify the existence of a glueball through its decay property. The glueball is quark flavor singlet, which should decay to $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ equally. However, the claimed “unique” feature of quark flavor singlet, is not unique, since the quark-antiquark state can also be flavor SU(3) singlet. Thus, it is not a firm evidence for a glueball. Furthermore, it is very likely that the glueball mix with the quark-antiquark scalar state and they together form several physical mesons. On the theoretical side, there are large ambiguities on the mixing mechanism [3]. This makes the study even more complicated.

Recently, another important direction to uncover the mysterious structure of scalar mesons, is discussed, which investigates the scalar meson production property through B meson decays. In B meson decays, the O_{8g} operator has a large Wilson coefficient, which could produce a number of gluons. These gluons in the final state may have the tendency to form a glueball state, thus the glueball production in inclusive B decays has attracted some theoretical interest [4, 5]. In a recent study [6], we calculate the transition form factors of B meson decays

into a scalar glueball in the light-cone formalism. Compared with form factors of B to ordinary scalar mesons, the B -to-glueball form factors have the same power in the expansion of $1/m_B$. Taking into account the leading twist light-cone distribution amplitude, we find that they are numerically only a little smaller than those form factors of B to ordinary scalar mesons. It means that the production rate of glueball in B decays is quite copious.

The scalar meson can be produced in B decays by two gluon (glueball) and also an isosinglet $q\bar{q}$ pair (ordinary meson). In this paper, we will propose a method for experiments to measure the nonzero two gluon contribution, so that to prove the existence of a scalar glueball cleanly. This will require the detection of scalar meson production from B_c decays.

THE STUDY OF MIXING BETWEEN GLUEBALL AND QUARK STATES

Up to the leading Fock state, a glueball is made up of two constituent gluons. In exclusive B decays, these two gluons can be emitted from either the heavy b quark or the light quark. In the expansion of α_s , the lowest order Feynman diagrams for form factors of B decays into a scalar glueball are depicted in Fig. 1 (a), (b) and (c). In Fig. 1 (d) and (e), the light antiquark in B meson and the energetic quark from the electro-weak vertex also form an isospin or SU(3) singlet scalar meson. Usually, people believe that the form factor of B decays to an ordinary scalar meson is larger than that of B decays into a scalar glueball. Our recent study shows [6] that the form factors of B decays into a scalar glueball is big enough for the experiments to observe it. Compared with our previous studies [7, 8] on the transition form factors of B mesons decays into ordinary scalar mesons (denoted as f_0 with the mass around 1.5 GeV), the $B \rightarrow G$ form factors are at the same order of magnitude. The B -to-glueball form factors are only a factor of two smaller than the $B \rightarrow \pi$ form factors. These form factor results are collected in

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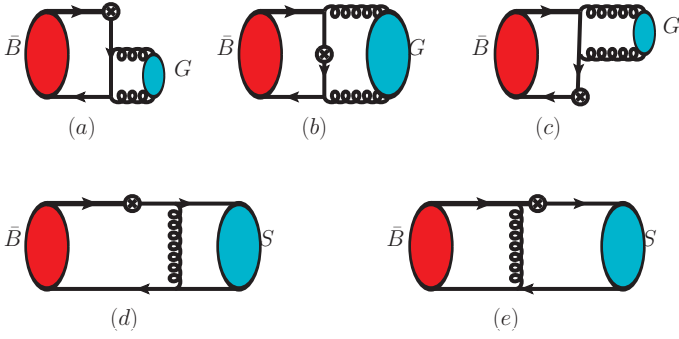


FIG. 1: Feynman diagrams of \bar{B} decays into a scalar glueball G and an ordinary scalar meson. The \otimes denotes the possible Lorentz structure arising from the electroweak interactions.

TABLE I: B to glueball (G), B to ordinary scalar meson (f_0) and B to pseudoscalar meson (π) transition form factors in the PQCD approach

	$F_0(0) = F_1(0)$	$F_T(0)$
$B \rightarrow G$	$0.11^{+0.02}_{-0.02}$	$0.05^{+0.01}_{-0.01}$
$B \rightarrow \pi$	$0.22^{+0.04}_{-0.05}$	$0.27^{+0.05}_{-0.06}$
$B \rightarrow f_0$ Scenario I	$-0.30^{+0.08}_{-0.09}$	$-0.39^{+0.10}_{-0.11}$
$B \rightarrow f_0$ Scenario II	$0.63^{+0.23}_{-0.14}$	$0.76^{+0.37}_{-0.17}$

table I for comparison¹. In fact, the main decay channel of a scalar glueball is $\pi\pi$ or $K\bar{K}$. Thus a scalar glueball is much easier to detect than the iso-singlet pseudoscalar meson such as η . Compared with the recently measured semileptonic $B \rightarrow \eta$ decay [9]

$$\mathcal{B}(B^- \rightarrow \eta l^- \bar{\nu}) = (3.1 \pm 0.6 \pm 0.8) \times 10^{-5}, \quad (1)$$

the branching ratio of $B \rightarrow Gl\bar{\nu}$ [6] is comparable with that of $B \rightarrow \eta l\bar{\nu}$ decay and may be observed on the ongoing B factories. It is very likely for the forthcoming Super B factory to observe a pure glueball, if it exists.

However, there is not any solid experimental evidence for a pure glueball state up to now. The reason may be that the glueball state can mix with the ordinary meson through the strong interactions. For example, the Lattice QCD collaboration predicted the mass of a scalar glueball ground state around 1.5-1.8 GeV. It is very likely that the glueball state mix with the ordinary quark-antiquark state and they form several physical mesons. In this mass region, there are three scalar mesons: $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$, which might be the potential candidates.

The mixing matrix can be set as

$$\begin{pmatrix} f_0(1710) \\ f_0(1500) \\ f_0(1370) \end{pmatrix} = \begin{pmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{pmatrix} \begin{pmatrix} G \\ \bar{s}s \\ \bar{n}n \end{pmatrix}. \quad (2)$$

For each physical scalar meson for example $f_0(1370)$, which is a mixture of glueball and ordinary states, the coefficients c_1 , c_2 and c_3 satisfy the normalization condition

$$\sqrt{|c_1|^2 + |c_2|^2 + |c_3|^2} = 1. \quad (3)$$

A non-zero c_1 would be a clear evidence for the existence of a glueball. Let us aim this to see if there is a way to settle it in B decays. The semileptonic $B \rightarrow f_0 l\bar{\nu}$ decays receive contributions from the $\bar{n}n$ component but without $\bar{s}s$ component (at least negligible), while the semileptonic $B_s \rightarrow f_0 l^+ l^-$ channel only receive contributions from the $\bar{s}s$ but without $\bar{n}n$ component. Both of the decay channels can receive gluon component contributions. Thus from eq.(3), we notice that the two independent mixing parameters can be fitted from the above two experimental measurements, in principle. For the three kinds of f_0 's, we have altogether 6 experiments, but only three real parameters in eq.(2) to be fixed. Since the branching fraction of $B_s \rightarrow f_0 l^+ l^-$ is expected to have the order of 10^{-8} or even smaller, one needs to accumulate a large number of B decay events. This could be achieved on the future experiments such as the Super B factory.

Semileptonic B decays are clean but in $B \rightarrow f_0 l\bar{\nu}$, the neutrino is identified as missing energy and the efficiency is limited; while the $B_s \rightarrow f_0 l^+ l^-$ has a small branching ratio. In these decays, the lepton pair does not carry any SU(3) flavor and the decay amplitudes receive less pollution from the strong interactions. The lepton pair can also be replaced by a charmonium state such as J/ψ since J/ψ does not carry any light flavor either. $B \rightarrow J/\psi f_0$ decays may provide another ideal probe to detect the internal structure of the scalar mesons. In $B \rightarrow J/\psi f_0$ decay, the $\bar{s}s$ component will not contribute at the leading order in α_s . For example, the $B \rightarrow J/\psi \phi$ decay has been set a very stringent upper limit [10]: $\mathcal{B}(B \rightarrow J/\psi \phi) < 9.4 \times 10^{-7}$. Thus $B \rightarrow J/\psi f_0$ decay can filter out the glueball component and the $\bar{n}n$ component of a scalar meson. Meanwhile in $B_s \rightarrow J/\psi f_0$ decay, only the $\bar{s}s$ and the gluon component contributes. Moreover, the final mesons in these channels are easy to reconstruct and these channels could have sizable branching fractions. If we use the factorization method, decay amplitudes are given as

$$A(\bar{B}^0 \rightarrow J/\psi f_0) = \frac{G_F}{\sqrt{2}} V_{cb} V_{cd}^* m_B^2 f_{J/\psi} a_2 F_1^{B \rightarrow f_0}(m_{J/\psi}^2). \quad (4)$$

The Wilson coefficient a_2 can be extracted from the $B \rightarrow$

¹ If scalar mesons f_0 are identified as $\bar{q}q$ excited states, referred as scenario I, the decay constants of f_0 are negative and so are $B \rightarrow f_0$ form factors. In scenario II, where scalar mesons f_0 are identified as $\bar{q}q$ ground state, the form factors are positive.

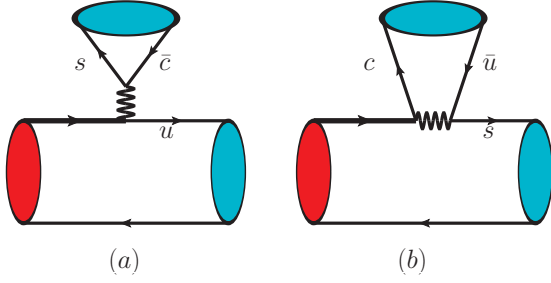


FIG. 2: Feynman diagrams of $B \rightarrow f_0 D$ decays.

$J/\psi K$ decays [14]

$$\mathcal{B}(\bar{B}^0 \rightarrow J/\psi \bar{K}^0) = (8.71 \pm 0.32) \times 10^{-4}. \quad (5)$$

The branching ratios are roughly predicted as

$$\mathcal{B}(\bar{B}^0 \rightarrow J/\psi f_0(\bar{n}n)) \simeq \begin{cases} (23^{+12}_{-14}) \times 10^{-6} & \text{S1} \\ (10^{+7}_{-5}) \times 10^{-5} & \text{S2} \end{cases}, \quad (6)$$

$$\mathcal{B}(\bar{B}^0 \rightarrow J/\psi G) \simeq (6.2 \pm 2.2) \times 10^{-6}, \quad (7)$$

where we have assumed the same q^2 dependence for all form factors and $F_1^{B \rightarrow K}(0) = 0.3$. The uncertainties are from the experimental data for $\mathcal{B}(B \rightarrow J/\psi K)$ and the $B \rightarrow S$ form factors at the $q^2 = 0$ point. For the B_s decays, the branching ratios are comparable with that of $B \rightarrow J/\psi K$:

$$\mathcal{B}(\bar{B}_s \rightarrow J/\psi f_0(\bar{s}s)) \simeq \begin{cases} (6.5^{+4.0}_{-4.5}) \times 10^{-4} & \text{S1} \\ (3.5^{+2.3}_{-1.4}) \times 10^{-3} & \text{S2} \end{cases} \quad (8)$$

$$\mathcal{B}(\bar{B}_s \rightarrow J/\psi G) \simeq (9.7 \pm 3.9) \times 10^{-5}. \quad (9)$$

Such large branching fractions offer a great opportunity to probe structures of scalar mesons. With the available data in the future, the mixing problem between the scalar mesons will be solvable and the glueball component can be projected out in principle.

If the power-suppressed annihilation diagrams are neglected, the charmful decays of B meson, $B \rightarrow f_0 D$, can also be used to constrain the mixing between scalar mesons. For instance in $B^- \rightarrow D_s^- f_0$, the $\bar{n}n$ and gluon component contribute but the $\bar{s}s$ component does not, while in $\bar{B}_s \rightarrow D^0 f_0$, the $\bar{n}n$ component will not contribute, as shown in Fig. 2. Thus the mixing coefficients can also be determined if these two channels are experimentally measured. It is necessary to point out that this method may suffer from sizable uncertainties of annihilation diagrams [7].

To be more specific, we will discuss two mixing mechanisms in detail. Because the decay width of $f_0(1500)$ is not compatible with the ordinary $\bar{q}q$ state, Amsler and Close claimed that $f_0(1500)$ is primarily a scalar glueball [11]. In the subsequent studies, they extracted the

mixing matrix through fitting the data of two-body decays of scalar mesons [12]:

$$\begin{pmatrix} f_0(1710) \\ f_0(1500) \\ f_0(1370) \end{pmatrix} = \begin{pmatrix} 0.36 & 0.93 & 0.09 \\ -0.84 & 0.35 & -0.41 \\ 0.40 & -0.07 & -0.91 \end{pmatrix} \begin{pmatrix} G \\ \bar{s}s \\ \bar{n}n \end{pmatrix} \quad (10)$$

Based on the SU(3) assumption for scalar mesons and the quenched LQCD results, Cheng et al. [13] reanalyze all existing experimental data and fit the mixing coefficient as

$$\begin{pmatrix} f_0(1710) \\ f_0(1500) \\ f_0(1370) \end{pmatrix} = \begin{pmatrix} 0.93 & 0.17 & 0.32 \\ -0.03 & 0.84 & -0.54 \\ -0.36 & 0.52 & 0.78 \end{pmatrix} \begin{pmatrix} G \\ \bar{s}s \\ \bar{n}n \end{pmatrix}. \quad (11)$$

It is found that the $f_0(1710)$ tends to be a primary glueball. This is very different from the first matrix of mixing coefficients in (10). The scalar meson production rates in B meson decays can be used to distinguish these assignments, starting with the $B \rightarrow S$ form factors collected in Tab. I. For example in scenario I, if we use the mixing coefficients in Eq. (10), the production rates of $f_0(1710)$ and $f_0(1500)$ in B decays are much smaller than that of $f_0(1370)$ but they have large and comparable production rates in B_s decays; if we use the mixing coefficients in Eq. (11), $f_0(1710)$ has small production rates in both B and B_s decays but the other two mesons have large and comparable production rates in B and B_s decays. Based on our predictions on form factors [6, 7, 8], these differences in B and B_s decays are helpful to distinguish the two mixing matrix.

GLUEBALL PRODUCTION IN B_c DECAYS

The ordinary light scalar meson is isospin singlet and/or flavor SU(3) singlet, while the glueball is flavor SU(6) singlet. Therefore it is difficult to distinguish them by the light u , d and s quark coupling. However, the light ordinary scalar meson has negligible $c\bar{c}$ component, while the glueball have the same coupling to $c\bar{c}$ as that to the $u\bar{u}$, $d\bar{d}$ or $s\bar{s}$. A clean way to identify a glueball is then through the $c\bar{c}$ coupling to the glueball.

In B decays, the initial heavy meson contains a light quark, thus contributions of the gluon component always accompany with the quark content $\bar{n}n$ or $\bar{s}s$. It is not easy to isolate the gluon content. The situation in the doubly-heavy B_c meson is different: it contains a heavy charm antiquark. The semileptonic $B_c \rightarrow f_0 l \bar{\nu}$ decays would happen only through Fig. 1(a)(b) and (c) but not through Fig. 1(d) and (e). The observation of this decay channel in the experiments will surely establish the existence of a scalar glueball. Moreover the CKM matrix element in this channel is V_{cb} , thus the $B_c \rightarrow f_0 l \bar{\nu}$ will have a sizable branching ratio. This channel will depend on the $B_c \rightarrow G$

transition form factor which requires the less-constrained B_c meson's light-cone distribution amplitude. But even if we assume the form factor of $B_c \rightarrow G$ is smaller than the $B_c \rightarrow \eta_c$ form factor by one order, branching ratios of $B_c \rightarrow Gl\bar{\nu}(l\bar{\nu})$ are suppressed by two orders

$$\mathcal{B}(B_c \rightarrow Gl\bar{\nu}) \sim 1\% \times 0.01 = 10^{-4}, \quad (12)$$

where the branching ratio of $B_c \rightarrow \eta_c l\bar{\nu}$ has been taken as 1%. This branching ratio is large enough for the experiments. One only needs to reconstruct the f_0 scalar meson in the final state and also the B_c meson mass in the intermediate state, so that to make sure that the scalar meson is produced from two gluons. That experiment is achievable even if the f_0 meson is not a pure glueball, but at least has a large portion of it.

$B_c \rightarrow f_0 \pi^-$ is another potential mode to figure out the gluon content. But in this mode, the $\bar{n}n$ component also contributes through the annihilation diagrams. The b and \bar{c} quark annihilates and the d and \bar{u} quark are created. The CKM matrix element V_{cb} and the Wilson coefficient a_1 are the same with the emission diagram for the B_c -to-glueball transition. The offshellness of the two internal particles in annihilation diagrams are of the order $m_{B_c}^2$. The electroweak vertex is the $V - A$ type and the decay amplitude is proportional to the light quark mass. Thus the decay amplitudes via annihilation diagram for the $\bar{n}n$ component are expected to be suppressed. As a result, the $B_c \rightarrow f_0 \pi^-$ also filters out the gluon component of the scalar meson as an approximation.

SUMMARY

Although the B -to-glueball form factors are small, they can not be neglected and more interestingly these form factors may have different interferences with those for the quark content, according to different descriptions of scalar mesons. If a scalar meson is a mixture of a glueball and an ordinary meson, we investigate the possibility to extract the mixing mechanism from semileptonic B decays. Semileptonic $B \rightarrow f_0 l\bar{\nu}$ and $B_s \rightarrow f_0 l^+ l^-$ decays can be used to determine the internal structures. The nonleptonic $B \rightarrow J/\psi f_0$ and $B_s \rightarrow J/\psi f_0$ decays are also analyzed. To avoid the interference between the quark and the gluon component, we find that the $B_c \rightarrow f_0 l\bar{\nu}$ and $B_c \rightarrow f_0 \pi^-$ will project out the gluon component of a scalar meson cleanly. Our results can be generalized to the other glueballs.

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- [1] E. Klempt and A. Zaitsev, Phys. Rept. **454**, 1 (2007) [arXiv:0708.4016 [hep-ph]];
D. M. Asner *et al.*, arXiv:0809.1869 [hep-ex];
V. Crede and C. A. Meyer, Prog. Part. Nucl. Phys. **63**, 74 (2009) [arXiv:0812.0600 [hep-ex]].
 - [2] G. S. Bali, *et al.* [UKQCD Collaboration], Phys. Lett. B **309**, 378 (1993);
H. Chen, J. Sexton, A. Vaccarino and D. Weingarten, Nucl. Phys. Proc. Suppl. **34**, 357 (1994);
C. J. Morningstar and M. J. Peardon, Phys. Rev. D **60**, 034509 (1999) ;
A. Vaccarino and D. Weingarten, Phys. Rev. D **60**, 114501 (1999) ;
C. Liu, Chin. Phys. Lett. **18**, 187 (2001);
D. Q. Liu, J. M. Wu and Y. Chen, High Energy Phys. Nucl. Phys. **26**, 222 (2002) ;
N. Ishii, H. Suganuma and H. Matsufuru, Phys. Rev. D **66**, 014507 (2002) ;
M. Loan, X. Q. Luo and Z. H. Luo, Int. J. Mod. Phys. A **21**, 2905 (2006) ;
Y. Chen *et al.*, Phys. Rev. D **73**, 014516 (2006) ;
 - [3] S. Spanier, N.A. Törnqvist, and C. Amsler, note on scalar mesons, review published on PDG.
 - [4] P. Minkowski and W. Ochs, Eur. Phys. J. C **39**, 71 (2005) [arXiv:hep-ph/0404194];
P. Minkowski and W. Ochs, arXiv:hep-ph/0304144.
 - [5] X. G. He and T. C. Yuan, arXiv:hep-ph/0612108.
 - [6] W. Wang, Y.L. Shen and C.D. Lu, e-Print: arXiv:0908.2216 [hep-ph].
 - [7] W. Wang, Y. L. Shen, Y. Li and C. D. Lu, Phys. Rev. D **74**, 114010 (2006) [arXiv:hep-ph/0609082].
 - [8] R. H. Li, C. D. Lu, W. Wang and X. X. Wang, Phys. Rev. D **79**, 014013 (2009) .
 - [9] B. Aubert *et al.* [BABAR Collaboration], arXiv:0808.3524 [hep-ex].
 - [10] Y. Liu *et al.* [Belle Collaboration], Phys. Rev. D **78**, 011106 (2008) [arXiv:0805.3225 [hep-ex]].
 - [11] C. Amsler and F. E. Close, Phys. Lett. B **353**, 385 (1995) [arXiv:hep-ph/9505219];
C. Amsler and F. E. Close, Phys. Rev. D **53**, 295 (1996) [arXiv:hep-ph/9507326].
 - [12] F. E. Close and A. Kirk, Phys. Lett. B **483**, 345 (2000) [arXiv:hep-ph/0004241];
F. E. Close and Q. Zhao, Phys. Rev. D **71**, 094022 (2005) [arXiv:hep-ph/0504043].
 - [13] H. Y. Cheng, C. K. Chua and K. F. Liu, Phys. Rev. D **74**, 094005 (2006) [arXiv:hep-ph/0607206].
 - [14] C. Amsler *et al.* [Particle Data Group], Phys. Lett. B **667**, 1 (2008).